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RESEARCH
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Evaluation of the Main Gun of the M60 Tank against Moving Ground Targets (U)

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DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

CRD/J

4 February 1966

SUBJECT: RAC-T-459, "Evaluation of the Main Gun of the M60 Tank against Moving Ground Targets (U)"

TO:

1. Transmitted herewith is (are) _______ copy (copies) of RAC-T-459, subject as above.

2. RAC-T-459 was prepared under contract DA-44-188-ARO-1 by the Research Analysis Corporation, McLean, Virginia, in conjunction with the study "Experimental Approaches for Small Units Engaged in Night Operations."

3. This publication documents an analysis of the employment of the main gun of the M60 Tank against moving ground targets. Data used was derived from a live-fire experiment conducted at Ft. Stewart, Georgia, during the period 25 June to 6 July 1963. The evaluation was undertaken primarily to obtain measures of hit probability as a function of ammunition muzzle velocity and to evaluate the desirability of altering lead doctrine to recognize the significant changes in muzzle velocity. Since the recommendations presented in RAC-T-459 are now included in substance in FM 17-12, distribution is being made for information only.

4. It is to be noted that the views presented in this publication represent those of the Research Analysis Corporation and that it is not an official Department of the Army publication.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:

Incl
as

HERALD B. GALLINGER
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FIELD EXPERIMENTS DIVISION
TECHNICAL MEMORANDUM RAC-T-459
Published June 1965

Evaluation of the Main Gun of the M60 Tank against Moving Ground Targets (U)

by
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FOREWORD

This paper evaluates employment of the main gun of the M60 tank against moving ground targets. The results are from a live-fire experiment conducted at Ft Stewart, Georgia, during the period 25 Jun—6 Jul 63.

Of chief interest are the hit probabilities against moving targets of armor-piercing discarding-sabot and training-practice rounds for the 105-mm main gun and the accuracy and consistency of observer sensings of firings of those ammunitions. However, such other intermediate results as miss distance and lay error are also reported because they support the results concerning hit probability.

Richard E. Tiller
Chief, Field Experiments Division

ACKNOWLEDGMENTS

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The excellent service and support of the RAC Electromechanical Laboratory for instrumentation and performance of duties over and above their normal function were immeasurably beneficial and greatly conducive toward assurance of satisfactory results. The efforts of Mr. Robert R. Redick and Mr. Arthur C. Smith of the Laboratory are specifically noted.

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The reduction of data and analysis were aided by the combined efforts of Miss Georgia Fleming, Mr. Stephen R. Wax, Mrs. Diane B. O'Keefe, Mrs. Jean L. Pickford, Mr. T. Donald Dixon, and Mr. John J. Turley, all of RAC.

To all these people the authors extend their sincere appreciation.

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Problem

To determine the hit probabilities of the main gun of the M60 tank against moving ground targets, as affected by (a) ammunition characteristics—particularly muzzle velocity, (b) lead doctrine, (c) target speed, (d) target range, and (e) direction of target movement.

Facts

To hit a moving target requires that the aiming point be selected with an anticipation of target location at time of projectile impact. This requirement, of aiming not where the target is but where the target will be, is called "lead." The longer the projectile flight time the greater is the difficulty of predicting target behavior and future position. Experience has shown that with ammunitions of muzzle velocities between 2000 to 3200 fps more first-round hits are obtained if the average gunner applies the first-round lead of 5 mils specified by standard doctrine. Of course, well-trained gunners with an understanding of ballistics vary their applied lead as a result of target behavior.

Because of increased muzzle velocities modern ammunition developments have significantly decreased projectile flight time to the extent that lead doctrine developed for lower-velocity ammunition may no longer be applicable. Additionally, range requirements for these modern ammunitions have become so stringent that average tank gunners cannot be provided with the experience necessary to enable them to adjust their lead requirements as the significant characteristics of the ammunition vary.

The present experiment was undertaken for two major purposes: (a) to obtain measures of hit probability (P_H) as a function of ammunition muzzle velocity and (b) to evaluate the efficacy of modernizing lead doctrine in consonance with the significant changes in muzzle velocity.

Discussion

An experiment designed to explore the problem was conducted at Ft Stewart, Ga., 25 Jun—6 Jul 63. To determine the ability of a person on the ground or in an adjacent tank to sense main-gun rounds independently by optical aids was a second objective of the experiment.

SUMMARY

Two types of 105-mm ammunition were tested: (a) training practice, tracer (TP-T) with ballistic characteristics similar to high-explosive plastic (HEP) with muzzle velocity of 2400 fps; and (b) armor-piercing discarding-sabot tracer (APDS-T) with muzzle velocity of about 4800 fps.

Two alternative lead doctrines were considered during experimentation: (a) standard doctrine, i.e., 5-mil first-round lead; and (b) modified doctrine, i.e., instructions on leading moving targets and specific leads required, by target speeds and ranges.

This paper presents hit probabilities of the M60 tank main gun (105 mm) against moving targets. In addition, measures of reliability and consistency of observer sensing as a possible means of fire adjustment are given. The experimental data provide the factual basis of the report.

Effective fire on a target depends largely on three factors: time for firing, accuracy of fire, and lethality of fire. The results of this paper are addressed to the first two factors—time for firing and accuracy of fire--with major emphasis on the latter. The lethality of fire is not considered here.

The 105-mm APDS-T round (muzzle velocity, 4800 fps) of the main tank gun has a high overall P_{HE} (0.39) against moving ground targets under the experimental conditions investigated. The observed hit probabilities of the M60 tank main gun using APDS-T ammunition against moving ground targets are shown in Table 1. Too few target hits were obtained to permit the development of a comparable tabular presentation for 105-mm TP-T ammunition under similar conditions.

TABLE 1

P_{HE}s of Main Gun of the M60 Tank against Moving Ground Targets

Factor investigated	Rounds fired	Target hits	P_{HE}
APDS-T Ammunition			
Lead doctrine			
Standard	46	14	0.30
Modified	47	22	0.47
Target speed			
5 mph	32	17	0.53
10 and 15 mph	61	19	0.31
Target range			
Near (730 m)	47	22	0.47
Far (1650 m)	46	14	0.30
Direction of target movement			
Left to right	47	24	0.51
Right to left	46	12	0.26
Overall	93	36	0.39
TP-T Ammunition[a]			
Overall	95	2	0.02

[a]Simulating HEP with muzzle velocity of 2400 fps.

SUMMARY

The use of a modified lead doctrine specifying lead requirements according to ammunition characteristics and estimated target speed and range has a significant effect on obtained hit probabilities. With APDS ammunition, the modified doctrine used in this experiment resulted in approximately 50 percent increased hit probabilities over those obtained when the standard lead doctrine was used.

Such other factors as target speed, target range, and direction of target movement have significant effects on hit probabilities.

Although ammunitions with muzzle velocities in excess of 3200 fps are extremely difficult or impossible to sense from the firing tank, sensings are significantly increased by observation from the ground or adjacent vehicles.

Conclusions

1. Ammunition muzzle velocities have a significant effect on hit probability against moving targets.
2. Significant changes in ballistic characteristics (especially muzzle velocities) require concomitant changes in fire doctrine to capitalize on potential increases in effectiveness.
3. Consideration of the factors of target speed, target range, and direction of target movement in the development of a modified lead doctrine will result in significantly higher hit probabilities against moving targets.
4. The use of a "buddy system" of fire adjustment in the development of fire doctrines can be expected to significantly increase subsequent-round hit probability.

Recommendations

1. Given adequate terminal effectiveness, the ammunition with the highest muzzle velocity should be utilized against moving targets.
2. Modification of lead doctrine based on significant changes in ammunition characteristics should be constantly considered and adjusted to fully utilize the technical improvements of ammunition.
3. The development of a fire doctrine based on sensing of high-velocity ammunition from the ground or adjacent vehicles should be considered to increase subsequent-round hit probabilities.

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Evaluation of the Main Gun of the M60 Tank against Moving Ground Targets

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ABBREVIATIONS

APDS-T	armor-piercing discarding-sabot, tracer
BC	Battery Commander
HEAT	high-explosive antitank
HEP	high-explosive plastic
P_{HE}	experimental hit probability
P_{HL}	lead-lay-error hit probability
P_{HT}	theoretical hit probability
TP-T	training practice, tracer

INTRODUCTION

Just as increased mobility is the present concept within all arms of the US Army, it is expected that the potential enemy realizes that arms lose effectiveness when employed against moving, as opposed to stationary, targets and has emphasized movement to a large degree. Thus in a modern war, an increasingly larger percentage of presented targets will be moving. The task of hitting a moving target imposes more stringent requirements on both the gunner and the ammunition required. Recent developments in ammunition have resulted in significant increases in muzzle velocities, which potentially ease the gunner's task and increase hit probabilities, especially against moving targets.

This paper presents the results of an investigation of some of the major factors—primarily, increased muzzle velocities and changes in lead doctrine—affecting hit probabilities against moving ground targets.

BACKGROUND

RAC initially investigated the lead problem in tank gunnery in July 1962 in Grafenwöhr, Germany, in conjunction with an evaluation of a gun-camera system.[1]

In the field test five tank gunners, operating independently, were required to simulate fire with an HEP round on crossing tanks moving at speeds between 10 and 30 mph at a range of 950 m. Since fire was simulated,[1] no information was available from burst on target or tracer to adjust the subsequent-round lead.

The camera data collected from experimentation with the 105-mm HEP round showed that four of the five tank gunners tested did actually lead moving targets relative to the apparent speed of the target although doctrine[2] prescribed a single lead (5 mils) on all moving targets. Figure 1 shows the results of this study.

It seemed to follow quite logically that the next step was to determine experimentally the hit probability of the M60 tank against controlled moving targets with live fire, utilizing both high- and low-velocity ammunition and operating both modified and standard lead doctrines.

Therefore in June–July 1963 a RAC team conducted the investigation of lead described in this paper, based on a field experiment with the M60 tank firing live ammunition against moving targets. The experiment was designed to evaluate the effects of ammunition type, lead doctrine, and such important

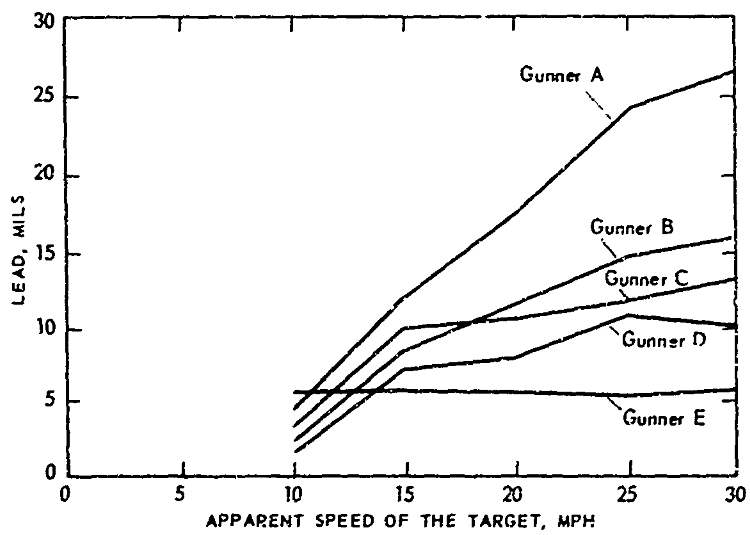


Fig. 1—Experimental Results, Five Gunners Leading Moving Targets
Range, 950 m; simulated HEP ammunition.

target-behavior characteristics as speed, range, and direction of movement on hit probabilities.

Another factor that warranted investigation was sensing as a means of fire adjustment. Sensing is accomplished by visually tracking the tracer element of the round in relation to the target and/or observing the impact or burst. The effectiveness of sensing as a means of fire adjustment has been unsatisfactory with ammunition having muzzle velocities exceeding 3200 fps.

The section "Observer Sensing" is presented as a basic investigation of the reliability and consistency of observer sensing as a means of fire adjustment and evaluates the ability of an observer adjacent to the firing tank to sense accurately the rounds fired.

SCOPE

The results of this investigation provide not only experimentally derived hit probabilities for low-velocity rounds (HEP, 2400 fps) and high-velocity rounds (APDS, 4800 fps) but also, more importantly, information bearing on the effects of the interactions among muzzle velocities, lead doctrines, and target behavior on expected hit probabilities. These data emphasize the importance of reevaluating doctrine in the light of significant changes in relevant weapons-performance characteristics.

The experimental factors tested in determining the hit probabilities against moving targets of the M60 tank's 105-mm main gun can be outlined as follows.

(a) Ammunition type: TP-T (simulated HEP), muzzle velocity 2400 fps; APDS-T, muzzle velocity 4800 fps.

(b) Lead doctrine: standard[2]; modified (see "Field Experiment")

(c) Target speed: 5 mph, 10 mph, and 15 mph.

(d) Target range (crossing): Near, 730 m; far, 1650 m.

(e) Direction of target movement: Left to right (L→R), right to left (L←R).

Since the investigation was limited to consideration of the M60 tank 105-mm gun against fixed-course crossing panel targets, the results are not intended to be representative of the tactical or combat environment but are intended to provide basic data pertaining to the problems associated with lead doctrine for moving targets in tank gunnery.

FIELD EXPERIMENT

DESIGN

A factorial experiment was conducted in order to examine the important interrelations of the independent variables tested. The factors of target range and target speed were randomized to counterbalance learning effects. The plan of the experiment is given in Fig. 2.

Lead doctrine	Speed, mph	Ammunition			
		APDS-T		TP-T	
		Range, m			
		130 (near)	1650 (far)	730 (near)	1650 (far)
		Direction of movement			
		L←R	L→R	L←R	L→R
Standard	5	–	–	–	–
	10	–	–	–	–
	15	–	–	–	–
Modified	5	–	–	–	–
	10	–	–	–	–
	15	–	–	–	–

Fig. 2—Experimental Plan

PROCEDURE

The subjects consisted of eight tank gunners qualified on the M60 tank. For the purpose of the experiment the subjects were divided into two equal groups. One group was instructed to employ the standard lead doctrine (one lead, 5 mils, for first-round firing); the other group was instructed to use a modified lead doctrine consisting of instruction on selection of a lead based on ammunition type and target behavior (target speed, range, and direction of movement). The information presented in Table 2 was supplied on a card to the gunners using the modified doctrine, for ready reference throughout the modified-doctrine firings. To avoid an interplay of knowledge between the two groups of gunners the standard-doctrine firings were conducted before the modified-doctrine firings. The required leads for hits of TP-T firings relative to changes in range and direction of movement were sufficient to cause the indicated differences in the modified doctrine for TP-T ammunition. However, the required leads for APDS-T ammunition of the modified doctrine did not vary sufficiently (one-half lead) relative to changes in target range and direction of movement.

TABLE 2

Modified Lead Doctrine

(To nearest ½ lead – 2½ mils)

Target speed, mph	105-mm ammunition				
	TP-T				APDS-T
	Target range, m				
	730		1650		
	Target direction				
	L→R	L←R	L→R	L←R	
5	½	½	½	1	0
10	1½	1½	1½	2	½
15	2	2	2	2½	1

Two tanks were employed on the firing line. One tank consistently fired 105-mm APDS-T ammunition and the other fired 105-mm TP-T. On each traverse of the figure-8 track, the tank firing APDS-T engaged the target at one range and the tank firing TP-T engaged the target at the other range.

In order to avoid target destruction, which would have resulted from live fire of the HEP round, ballistically matched TP-T ammunition simulated the HEP ammunition of muzzle velocity 2400 fps. The high-velocity ammunition in the field research was APDS-T, muzzle velocity 4800 fps.

The target speeds of 5, 10, and 15 mph were representative of the rates of movement expected in many tactical situations involving moving ground targets.

The tank crew utilized the standard tank fire command. At the time of the gunner's command of "on the way" the tank-mounted camera was started, recording the lead-lay of the gun, and continued recording for a few seconds. Each tank fired a maximum of two rounds during each firing engagement. After each traverse of the track the target was stopped and miss distances of target hits were recorded and marked; then the target speed was reset and the next scheduled trial was conducted. The order of experimental trials is shown in App C.

The order of trials was established in an effort to save time, minimize wear and tear on the track and target-towing equipment, and obtain realistic information.

Throughout the experimentation the gunners were not specifically informed as to the direction of movement of the target, target speed, or target range.

Instrumentation

The instrumentation employed in the experiment included tank-mounted cameras and time-event recorders. A 16-mm motion-picture camera (AN-N6 modified) and its accessory equipment were attached to the searchlight mountings of the M60 turret and boresighted, with routine checks to assure proper alignment. The camera was started manually and operated from the 24-v electrical system in the tank. An approximate 4-sec continuation of camera operation following the firing time was built into the camera to record the movement of the target during flight of the projectile.

Time events were recorded on an Esterline-Angus pen recorder. An impulse from each firing tank provided a pen record of the tank's time of fire. In addition, manually operated switches were used to record the specific times the target entered and moved out of the firing zone.

Battery Commander (BC) scopes were positioned on 4-ft towers to the rear of the firing tank for observers to sense firings. The rangefinder (M17c) of an adjacent nonfiring M60 tank served as another independent means of observer sensing.

A manually controlled motor car with calibrated throttle settings for approximate target speeds towed the target carriage car at scheduled speeds.

The moving target, fabricated from a 6- by 6-ft plywood panel with a centered black 2- by 2-ft cross, was mounted on a 6- by 4-ft flatcar. The use of a 30- by 15-ft shot-catcher directly behind the target to record misses during experimentation proved infeasible because of inadequacies in the condition of the track.

Range Layout

Existing tank range facilities for firing 105-mm APDS-T ammunition are limited. Fort Stewart is one of the few Army posts that possess a range fan of sufficient size for live firing of APDS-T ammunition. The moving-target range at Ft Stewart is a figure-8 track. The layout of the Table V moving-target tank range at Ft Stewart, Ga., utilized for experimentation is shown in Fig. 3. Two crossing ranges at 730 and 1650 m were used for the experimental firings. At either range the target was engaged over a path of 290 yd with each exit and entrance clearly indicated by markers. The two firing tanks were positioned approximately 50 ft apart on the firing line. At the command post, located about 50 yd from the firing line, were mechanical time recorders and direct communication with the target pit and firing line.

DATA COLLECTION

Four general classes of information composed the experimental output from the test: target data, sensing data, photographic data, and time data.

Target data supplied actual target hit-miss information and miss distance from center of mass of target hits.

Sensing data supplied visually aided tracking observations throughout the experimentation by (a) a military observer using a BC scope and (b) the tank commander of the adjacent M60 tank using the tank's rangefinder (M17c) for both APDS-T and TP-T firings.

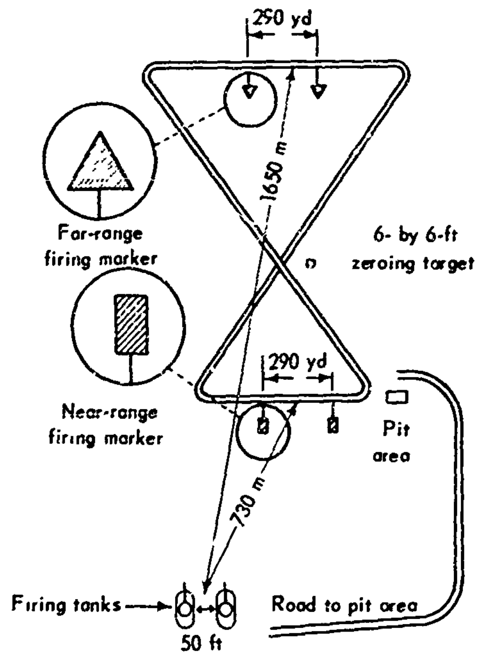


Fig. 3—Moving-Target Tank Firing Range at Ft Stewart, Ga.

Photographic data were collected in the form of 16-mm motion-picture film from the tank-mounted cameras. The angular lead-lay of the gun at the time of firing was thus obtained.

Time data were collected in the form of Esterline-Angus pen records. Times for firing the first and the second rounds of ammunition were obtained from the pen records. The approximate speed of the target was verified by the time required for the target to traverse the marked section of the track.

HIT PROBABILITY

INTRODUCTION

The probability of a main-gun round of the M60 tank striking a moving target was determined by three methods:

(a) Experimental hit probability (P_{HE}) is the ratio of the number of hits on a 6- by 6-ft target to the number of rounds fired. The P_{HE} discussed here does not reflect the "near-hits" that resulted from the live firings. A target "hit" was assigned a value of 1 and a target "miss" as 0; only these were considered.

(b) Lead-lay-error hit probability (P_{HL}) is based primarily on the horizontal miss distances determined from film-data analysis and calculated from the mathematical analysis (described in App A) that is itself derived from standard errors of such factors as range, drift, droop, and jump for ammunition types. The numerical values of P_{HL} are substantially different from the observed P_{HE} values in some cases. However, because an individual near-hit is assigned a P_{HL} that differs only slightly from actual hits on the edge of the target, the measure of P_{HL} is valid and worth while as a consideration. The errors of film data (such as parallax) and those in film readout (rounded to the nearest ½ mil) are responsible in part for the inconsistency between P_{HE} and P_{HL}. Nevertheless, certain trends, exhibited in the following pages, tend to add to the validity of the general P_{HL} results—particularly in the TP-T firings, where, because of inherent ballistic dispersion, observed target hits are sporadic.

(c) Theoretical hit probability (P_{HT}) is based on theoretical firings according to the specific lead doctrine for each type (TP-T and APDS-T) ammunition. The P_{HT} is examined in a following section, "Theoretical Hit Probability."

The detailed results in this chapter testify to the significant increases in hit probability caused by increased ammunition muzzle velocity and the modified lead doctrine. Thus, given adequate terminal effectiveness, the round having the highest muzzle velocity should be used against moving ground targets to increase hit probability.

The 105-mm APDS-T round (muzzle velocity, 4800 fps) has a high overall P_{HE} (0.39) against moving ground targets under the experimental conditions investigated. The observed hits for the two ammunition types are shown in Table 1; the APDS-T firings are subdivided further, according to the independent variables considered.

When using APDS-T ammunition the modified lead doctrine specifying lead requirements according to ammunition characteristics and estimated target speed and range resulted in approximately 50 percent increased hit probabilities over those obtained when using the standard lead doctrine.

The significant changes in ballistic characteristics (especially muzzle velocity, for example, between HEP and APDS) require changes in fire doctrine to capitalize on potential increases in effectiveness. To fully utilize the technical improvements of ammunition, modification of lead doctrine based on significant changes in ammunition characteristics should be constantly considered and adjusted.

TP-T AMMUNITION

P_{HE}

A total of 2 out of 95 TP-T rounds fired hit the 6- by 6-ft target. Both these hits were second-round firings under the modified lead doctrine at the near target range. Because of the scarcity of TP-T target hits, detailed analysis of P_{HE} for TP-T is insignificant and is not included.

The obvious result concerning the hit probability of the M60 tank main gun employing TP-T ammunition against moving ground targets is that the hit probability 105-mm TP-T ammunition was found to be quite low against moving targets.

P_{HL}

Main Effects. The results of an analysis of variance of the TP-T data showed three of the main effects of the factors investigated to be significant at levels of 0.05 or less. The factor of target range was found to have a significant effect at the 0.01 level of significance, whereas lead doctrine and target speed were significant sources of variation at the 0.05 and 0.025 levels, respectively. Table 3 shows the main effects of target range, lead doctrine, and target speed as the mean value of P_{HL} for the various levels of the respective factors. The percent increase or decrease is also listed as an estimate of the main effect of the factor relative to the specific change in levels.

The increase of target range from 730 to 1650 m significantly decreases the accuracy of the main gun against moving ground targets. The difference of the means in Table 3 is 0.24 for P_{HL}.

The use of the modified doctrine significantly increases the P_{HL} of the main gun by 0.10. A 50 percent decrease in P_{HL} for TP-T ammunition resulted from a 5-mph increase in target speed from 5 to 10 mph. Only a slight decrease of 0.02 in the mean P_{HL} resulted as target speed was increased from 10 to 15 mph.

Interactions. Three first-order interactions (doctrine-direction, range-speed, and speed-direction) were found to be significant at the 0.05 level or smaller. The means of these significant interactions are given in Table 4.

The decrease of mean P_{HL} from near-range firing to far-range firing by a factor greater than 5 resulted for all target speeds investigated. At the near

TABLE 3

Main Effects of Individual Factors on P_{HL} of M60 Tank Using 105-mm TP-T Ammunition Against Moving Targets

Factor	Mean P_{HL}	Percent increase (+) or decrease (–)	Level of significance
Target range, m			
Near, 730	0.27	–89	0.01
Far, 1650	0.03		
Lead doctrine			
Standard	0.11	+91	0.05
Modified	0.21		
Target speed, mph			
5	0.24	–50	0.025
10	0.12	–17[a]	
15	0.10		

[a] Not significant.

TABLE 4

Mean P_{HL} of 105-mm TP-T Ammunition for Significant First-Order Interactions

a. Target Speed—Target Range

Speed, mph	Range: Near	Range: Far	Level of significance
5	0.43	0.03	0.05
10	0.22	0.04	
15	0.15	0.02	

b. Target Speed—Target Direction

Speed, mph	Direction: L←R	Direction: L→R	Level of significance
5	0.21	0.28	0.05
10	0.16	0.02	
15	0.02	0.15	

c. Doctrine—Target Direction

Lead doctrine	Direction: L←R	Direction: L→R	Level of significance
Standard	0.14	0.08	0.025
Modified	0.14	0.30	

target range the decrease of mean P_{HL} as target speed increased is significant, whereas at the far target range the P_{HL} is quite low for all target speeds investigated.

As target speed increased a steady decrease in mean P_{HL} resulted for targets moving from right to left, whereas for targets moving from left to right a breakpoint seemed to be between the 5- and the 10-mph target speed.

The increase in mean P_{HL} resulting from the modified lead doctrine on firings at targets moving from left to right was greater than a factor of 3, from 0.08 under the standard lead doctrine to 0.30 for firings conducted under the modified lead doctrine.

Two second-order (three-factor) interactions were found to be significant. The interactions of doctrine, round, and range and doctrine, speed, and range were significant at the 0.01 level and at the 0.05 level respectively. The mean values of P_{HL} are listed in Table 5 for the significant second-order interactions.

TABLE 5

Mean P_{HL} of 105-mm TP-T Ammunition for Significant Second-Order Interactions

a. Doctrine—Round—Range

Lead doctrine	Round	Target range	
		Near	Far
Standard	1	0.19	0.02
	2	0.19	0.02
Modified	1	0.36	0.04
	2	0.48	0.05

b. Doctrine—Speed—Range

Lead doctrine	Target speed, mph	Target range	
		Near	Far
Standard	5	0.35	0.03
	10	0.21	0.03
	15	0.02	0.00
Modified	5	0.54	0.04
	10	0.24	0.05
	15	0.34	0.04

No increase in the average P_{HL} for second-round TP-T firings was exhibited under the standard lead doctrine at either the near or far target range. But under the modified lead doctrine a significant increase of 0.12 in mean P_{HL} was found for second-round firing at the near range. The ability of the gunner to adjust gun lay to compensate for initial gun-lay errors (smaller in the modified doctrine) determines whether an improved second round is fired.

Since the modified lead doctrine reduces the error of initial gun lay, improved second rounds will necessarily result.

The general decrease of P_{HL} as target speed increases to 5-10 mph is evident at the near target range in Table 5. The substantial increase of P_{HL} for firings under the modified doctrine is significant at the near target range, as compared with standard-doctrine results.

APDS-T AMMUNITION

P_{HE}

Main Effects. All main effects of the variables considered in the experimentation were found to be significantly different at the 0.10 level of significance or less in an analysis of variance of the APDS-T firing data. Table 6 gives the respective mean values for the main effects and also lists the percentage increase, or decrease, as an estimate of the main effect relative to the specific change in levels of the factor.

The changes in P_{HE} caused by the main effects are obviously explainable, with one exception. The employment of a lead doctrine that specifies lead according to ammunition muzzle velocity and target behavior characteristics will result in an increased hit probability. In the investigation described here, the modified lead doctrine resulted in over 50 percent increase in P_{HE}. As

TABLE 6

Main Effects of Individual Factors on P_{HE} of M60 Tank Using 105-mm APDS-T Ammunition against Moving Targets

Factor	P_{HE}	Percent increase (+) or decrease(–)	Level of significance
Lead doctrine			
Standard	0.30	+57	0.10
Modified	0.47		
Target range, m			
Near, 730	0.47	-36	0.10
Far, 1650	0.30		
Target speed, mph			
5	0.53	-51	0.05
10	0.26	+35[a]	
15	0.35		
Round			
1	0.29	+62	0.05
2	0.47		
Direction of target movement			
R→L	0.26	+96	0.01
L→R	0.51		

[a]Not significant.

target range increased, P_{HE} decreased. The increase of target range from 730 to 1650 m accounted for a 36 percent decrease in P_{HE}. The increased target speed from 5 to 10 mph accounted for a 51 percent decrease in P_{HE}; however, the P_{HE} values for target speeds of 10 and 15 mph were not significantly different, indicating that such a target speed increase will not seriously affect actual target hits. Although the sensing of APDS-T ammunition is extremely difficult, an increase of 62 percent in P_{HE} resulted from second-round firings (i.e., 14 first-round target hits compared to 22 second-round hits). The direction of target movement caused the change in P_{HE}, which is not obvious. When the direction of target movement was reversed from right-to-left to left-to-right, twice as many target hits (24 compared to 12) resulted, i.e., an increase of 0.25 in P_{HE}.

A hypothesis that may account for this unexpected difference is the inherent factor of drift in the round. The direction of target movement caused a 0.35 change in P_{HE} at the far target range (i.e., an increase from 3 target hits to 11 target hits for right-to-left direction compared with left-to-right, where the drift of the round is 0.2 m). Thus at the far target range the factor of drift increased the lead required for hits on targets moving from right to left and reduced the lead required for hits on targets moving from left to right. The data on the interactions of P_{HE} also support the hypothesis.

Interactions. In addition to the significant differences in the main effects, certain interactions of the various factors showed significant differences in the APDS-T firing data. Table 7 lists the interactions that were found to be significant and the respective levels of significance.

TABLE 7

Significant Interactions of APDS-T P_{HE}

Significant interaction	Level of significance
Target range—target speed	0.10
Target range—target speed—target direction	0.10
Round No.—doctrine—target speed	0.10
Doctrine—target range—speed—direction	0.10

The significant differences in P_{HE} of the target-range—target-speed interaction at the 0.10 level were found in the decrease of P_{HE} as target speed approaches 10 mph and target range increases.

The effect of the interaction of direction of movement and range at the 5-mph target speed was significant at the 0.10 level. Specific significant differences of combined round, lead doctrine, and target speed at the 0.10 level were also in the data at the low level of speed and at all levels of target speed and doctrine for second-round firings. The increase of P_{HE} for second-round firings under the modified doctrine adds to the belief that a reduced magnitude of the first-round miss under the modified lead doctrine results in a greater second-round hit probability, since less adjustment of first-round lay is necessary than under the standard lead doctrine.

The overall decrease in P_{HE} as target range increases is less for higher-speed targets than low-speed targets, but the factor of target direction has the effect of increasing P_{HE} when target movement from right to left is contrasted with the left-to-right movement. Not surprisingly, P_{HE} increases (a) in subsequent-round firings, (b) under modified lead doctrine, and (c) at lower target speed.

For the modified-doctrine firings subsequent-round firings demonstrated a significant increase in P_{HE} for higher target speeds.

The significant third-order interaction of doctrine-range-speed-direction exhibited the following general effects: modified lead doctrine and left-to-right target movement resulted in increased P_{HE} and increases in target speed and range resulted in decreased P_{HE}.

The greatest increase in P_{HE} of the four-factor interaction was found to be at the far target range when the direction of movement was from left to right.

P_{HL}

Main Effects. The analysis of variance of the APDS-T P_{HL} data showed four main effects to be highly significant causes of variation at the 0.10 significance level or lower. The significant main effects of target range, direction

TABLE 8

Main Effects of Individual Factors on Mean P_{HL} of M60 Tank Using 105-mm APDS-T Ammunition against Moving Targets

Factor	Mean P_{HL}	Percent increase (+) or decrease (−)	Level of significance
Lead doctrine			
Standard	0.24	+33	0.05
Modified	0.32		
Target range, m			
Near, 730	0.44	−75	0.0005
Far, 1650	0.11		
Target speed, mph			
5	0.31	− 3[a]	0.10
10	0.30	−27	
15	0.22		
Direction of target movement			
L←R	0.20	+75	0.0005
L→R	0.35		

[a]Not significant.

of target movement, lead doctrine, and target speed are given in Table 8 as the respective mean values of P_{HL}. The percentage increase or decrease is listed for each factor for an estimate of the main effect relative to the specific change in levels of the factor. The level of significance resulting from the analysis of variance of the APDS-T data is included in Table 8 for each significant factor.

Interactions. Three first-order (two-factor) interactions of speed and range, speed and direction, and range and direction were found to have highly significant effects on P_{HL}. Mean P_{HL} for these interactions are given in Table 9 with the level of significance indicated.

TABLE 9

Mean P_{HL} of 105-mm APDS-T Ammunition for Significant First-Order Interactions

a. Target Speed—Target Range

Speed, mph	Range		Level of significance
	Near	Far	
5	0.57	0.04	
10	0.46	0.14	0.0005
15	0.28	0.15	

b. Target Speed—Target Direction

Speed, mph	Direction		Level of significance
	L←R	L→R	
5	0.32	0.31	
10	0.18	0.42	0.01
15	0.10	0.34	

c. Target Range—Target Direction

Range	Direction		Level of significance
	L←R	L→R	
Near	0.32	0.55	0.05
Far	0.08	0.12	

The increase of target range significantly decreased the mean P_{HL} at both the 5- and the 10-mph target speeds. A significant decrease in average P_{HL} resulted from the increase of target speed from 5 to 10 mph at both target ranges investigated. The overall effect of interaction of speed and range was expected.

The significant increase of P_{HL} at 10 and 15 mph and also at the two target ranges when the target movement was reversed from right-to-left to left-to-right was unexpected. The difficulty of reversing the moving target's direction probably restricts such procedure during tank gunnery practice, thereby causing the inherent parallax error to bias resulting hit probability.

The second-order (three-factor) interactions of range-speed-direction, range-speed-doctrine, and range-direction-doctrine were found to be significant causes of variation. The mean values of P_{HL} for these interactions are listed in Table 10 with the level of significance of each interaction.

TABLE 10

Mean P_{HL} of 105-mm APDS-T Ammunition for Significant Second-Order Interactions

a. Range—Speed—Direction

Direction of target movement	Target speed, mph	Target range: Near	Target range: Far	Level of significance
L→R	5	0.58	0.04	0.005
	10	0.58	0.26	
	15	0.51	0.12	
L←R	5	0.56	0.04	
	10	0.34	0.02	
	15	0.02	0.18	

b. Range—Speed—Doctrine

Lead doctrine	Target speed, mph	Target range: Near	Target range: Far	Level of significance
Standard	5	0.54	0.00	0.10
	10	0.41	0.14	
	15	0.29	0 00	
Modified	5	0.60	0.08	
	10	0.51	0.15	
	15	0.28	0.28	

c. Range—Direction—Doctrine

Lead doctrine	Direction of target movement	Target range: Near	Target range: Far	Level of significance
Standard	L→R	0.51	0.10	0.0005
	L←R	0.30	0.00	
Modified	L→R	0.60	0.17	
	L←R	0.34	0.16	

Of course, the effect of increasing target range from 730 (near) to 1650 m (far) significantly decreases P_{HL}. However, the unexpected decrease in P_{HL}, at the near range and at all speeds, due to reversing the direction of target movement deserves special attention (see Table 10a). The effect of target direction must also be pointed out in the results shown in Table 10c. The significant increase in mean P_{HL} caused by the modified lead doctrine, particularly at the far target range, is again demonstrated in Table 10b.

In general the obvious results may be summarized as follows:

Table 10 shows several inconsistencies of P_{HL} at the far range. However, at the near target range, the means point out the decreases in P_{HL} as target speed increases to 10 and 15 mph and the general decrease (with some exceptions) of P_{HL} caused by increased target range, as is well known and expected. The use of a modified lead doctrine has the effect of a significant increase at the far range in average P_{HL} as contrasted with the far-range averages with the standard lead doctrine. Left-to-right target movement gives higher mean values of P_{HL} than right-to-left target movement, with the effect of increased target range generally causing a decrease in P_{HL}.

THEORETICAL HIT PROBABILITY

Theoretical hit probability (P_{HT}) is based on theoretical firing of the round according to the given lead doctrine (either standard or modified) and on subsequent computations of the hit probability on a 6- by 6-ft target; the latter is a function of such factors as drift, droop, and jump for ammunition types.[3,4] Since necessary adjustments of initial gun lay for second-round firing are prescribed doctrine, results of subsequent-round firings are precluded.

The values of P_{HT} for the 105-mm TP-T and APDS-T rounds were computed from (a) specific leads supplied under the modified lead doctrine and (b) the single 5-mil lead of the standard lead doctrine for various M60 tank moving-target engagements at the investigated variations of target range, speed, and direction of movement.

TABLE 11

P_{HT} for the 105-mm Main Gun of the M60 Tank against Moving Targets

Lead doctrine	Target speed, mph	Direction of target movement and range			
		L→R		L←R	
		Near	Far	Near	Far
		TP-T Ammunition			
Standard	5	0.38	0.05	0.45	0.07
	10	0.18	0.06	0.13	0.03
	15	0.00	0.01	0.00	0.00
Modified	5	0.48	0.06	0.40	0.03
	10	0.61	0.06	0.62	0.06
	15	0.50	0.07	0.44	0.04
		APDS-T Ammunition			
Standard	5	0.01	0.00	0.00	0.00
	10	0.39	0.01	0.08	0.04
	15	0.79	0.30	0.66	0.35
Modified	5	0.14	0.07	0.51	0.03
	10	0.52	0.30	0.79	0.20
	15	0.79	0.30	0.66	0.35

An average increase of 0.17 in P_{HT} due to the use of the modified rather than the standard lead doctrine is exhibited in Table 11. The mathematical analysis of theoretical hit probability is included in App A. The computed values of P_{HT} are given in Table 11 for both TP-T and APDS-T ammunition.

OBSERVER SENSING

A great deal of emphasis has been placed on sensing as a means of fire adjustment. With kinetic-energy rounds this is done largely by means of sensing the tracer in relation to the target; with chemical-energy rounds, by sensing the burst in relation to the target. How effective sensing is as a means of fire adjustment has been open to question. Sensing may, however, inform the firer of the correct direction of change if he is unable to determine the degree of change necessary.

BACKGROUND

The introduction of rounds with muzzle velocities exceeding 3200 fps makes sensing of rounds by the firer a most difficult, if not impossible, task.[5] It therefore becomes most important that fire doctrines be developed for these rounds along lines not requiring either the gunner or the commander of the firing tank to make adjustments on the basis of his own sensing. To meet this problem, a method of fire adjustment based on the "buddy system" was investigated; in this system, Tanks A and B would operate as a fire team, with Tank Commander A sensing the rounds of Tank B and adjusting B's fire while Tank Commander B senses A's rounds and adjusts A's fire. Whether such a method could be more expedient as a rapid means of destroying enemy tank targets than some other non-sensing fire-adjustment technique is yet to be determined. To determine the potential effectiveness of this method of fire adjustment, data on the reliability and accuracy of sensing by use of both a BC scope and an adjacent tank's rangefinder were obtained throughout the lead experiment.

FINDINGS

Table 12 gives the overall summary of observer sensing for firings of both APDS-T and TP-T ammunition. Correct sensing of rounds by observers is defined as (a) an actual target hit sensed by the observer as a hit, and (b) an actual target miss sensed as a miss. The latter is determined by correctly sensing an actual underlead or overlead of the moving target.

The results were found to be statistically significant at the 0.02 level of significance that the data of observer sensing of APDS-T ammunition were

TABLE 12

Summary of Observer Sensing of Firings of 105-mm Ammunition from the M60 Tank against Moving Ground Targets

Observer's visual aid	Correct sensing					
	Target hits			Target misses		
	Number	Number sensed	Percent sensed	Number	Number sensed	Percent sensed
			APDS–T Ammunition			
Rangefinder	20	15	75	17	12	71
BC scope	36	16	44	44	30	68
			TP–T Ammunition			
Rangefinder	2	2	100	23	10	44
BC scope	2	2	100	70	38	54

not due to chance. The resulting conclusion is that observer sensing of high-velocity ammunition utilizing visual aids is advantageous in significantly increasing subsequent-round hit probability.

No significant difference in subsequent-round hits could be expected from the observer sensings of TP-T firings with and without visual aids.

The development of a fire doctrine based on the "buddy system" for sensing high-velocity ammunition should be considered in order to increase subsequent-round hit probability.

HORIZONTAL MISS DISTANCE

The photographic data in conjunction with the time data obtained from the experiment formed the basis for determination of horizontal miss distance. The detailed methodology of the computations is contained in App A.

Arithmetic Measurements

The overall means and standard deviations of the horizontal miss distances are given in Table 13 for both APDS-T and TP-T ammunition.

TABLE 13

Measures of Horizontal Miss Distance, 105-mm Main Gun of the M60 Tank against Moving Targets

(+ = ahead of target, − = behind target)

Factor	Ammunition			
	APDS-T		TP-T	
	Mean miss distance, m	Standard deviation	Mean miss distance, m	Standard deviation
Lead doctrine				
Standard	-0.20	4.33	-2.10	8.16
Modified	-0.42	2.47	-1.55	4.31
Round				
1	-0.17	3.62	-2.81	6.14
2	-0.49	3.50	-0.60	7.37
Target speed, mph				
5	-0.31	3.53	+0.64	7.24
10	+0.62	3.90	-3.09	4.55
15	-1.12	3.17	-3.37	7.62
Target range				
Near	-0.16	1.58	-2.18	3.07
Far	-0.47	4.92	-1.53	9.15
Direction of target movement				
L→R	+0.41	3.37	-1.42	8.20
L←R	-1.02	3.63	-2.24	5.26

For APDS-T, only the means of direction of target movement indicate any statistically significant difference (0.10 level). But the outstanding differences appear in two cases in the standard deviations, not in the means. The modified doctrine resulted in a 40 percent reduction of the standard deviation, as compared with the standard-doctrine firings. Also, as is expected, the increase of range from 730 (near) to 1650 m (far) has the effect of increasing the standard deviation around the mean horizontal miss distance by a factor of three.

In the case of firings employing TP-T ammunition, statistically significant differences in the mean horizontal miss distances were not outstanding in the data. As expected, the mean miss distances for TP-T firings were larger than for APDS-T firings in all cases, as were the standard deviations.

Absolute Measurements

A more representative measure of horizontal miss distance is the absolute value. The overall means and standard deviations of the absolute horizontal miss distance are given in Table 14 for firings of both APDS-T and TP-T ammunition against moving targets.

TABLE 14

Measures of Absolute Horizontal Miss Distance, 105-mm Main Gun of the M60 Tank against Moving Targets

Factor	Ammunition			
	APDS-T		TP-T	
	Mean miss distance, m	Standard deviation	Mean miss distance, m	Standard deviation
Lead doctrine				
Standard	3.38	2.67	5.87	5.95
Modified	1.65	1.86	2.97	3.39
Round				
1	2.61	2.48	5.31	4.92
2	2.49	2.47	4.66	5.67
Target speed, mph				
5	2.52	2.44	3.56	6.11
10	2.72	2.81	4.11	3.56
15	2.46	2.24	6.29	5.33
Target range				
Near	1.15	1.07	2.53	2.78
Far	4.12	2.63	6.78	6.10
Direction of target movement				
L→R	2.17	2.59	5.59	6.08
L←R	2.95	2.30	3.79	4.25

The larger ballistic dispersion of TP-T ammunition in comparison with APDS-T ammunition is pointed out in the comparisons of the standard deviations of the horizontal miss distances for the two types of ammunition in Fig. 4.

As was the case in the arithmetical measures of miss distance (see Table 13), the consistent increase of the mean miss distances and standard deviations of TP-T ammunition as compared to APDS-T ammunition is obvious for the absolute miss distances in Table 14.

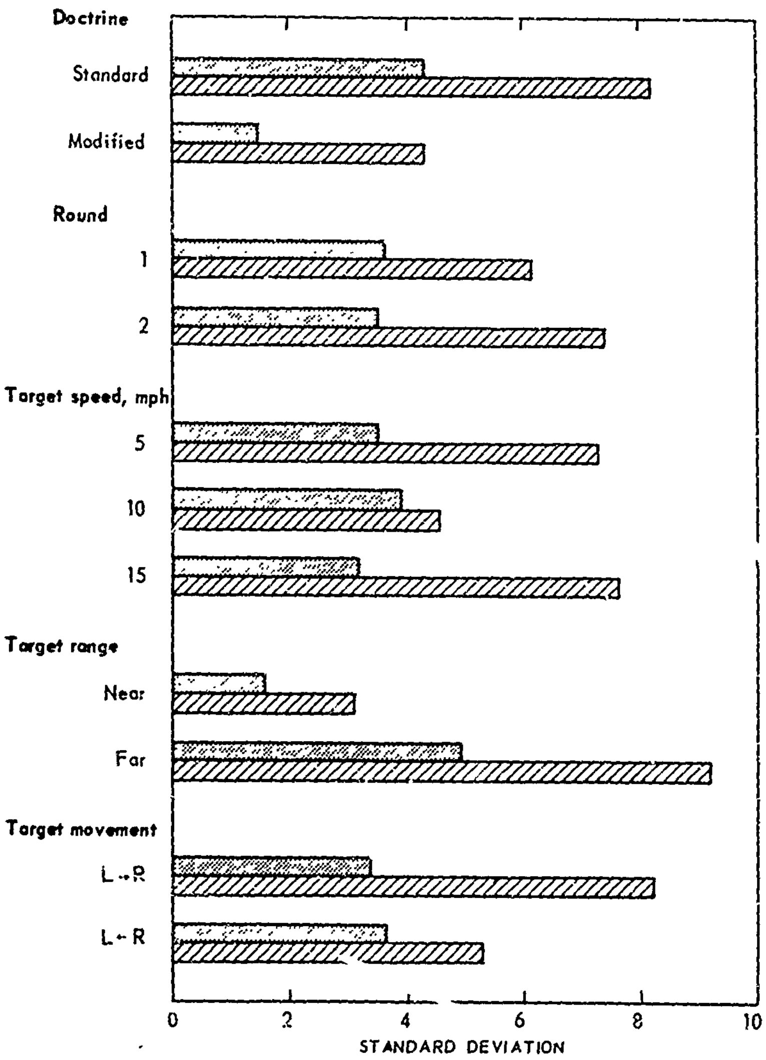


Fig. 4—Comparisons of Standard Deviations of Horizontal Miss Distances for Firings of 105-mm APDS-T and TP-T Ammunition

M60 tank against moving targets.

APDS-T TP-T

TABLE 15

Percentages of Firings Terminating ahead of Aiming Point, M60 Tank Main Gun against Moving Targets

Factor	105-mm ammunition type	
	APDS-T	TP-T
	Overlead, %	
Lead doctrine		
Standard	48	32
Modified	42	32
Target range		
Near	50	27
Far	39	38
Target speed, mph		
5	48	39
10	51	29
15	35	29
Round		
1	48	27
2	41	39
Direction of target movement		
L→R	50	30
L←R	39	34

Overlead

In Table 13 the large number of negative means, indicating an underlead, is outstanding. For APDS-T and TP-T firings the incidence of underlead was observed in the majority of firings. Overleads were observed in 32 percent of the cases for TP-T firings and 45 percent for APDS-T firings. Table 15 gives a synopsis of the percentages of overleads by factors investigated for both ammunitions used in the experiment.

TIME FOR FIRING

In some cases the time data collected under experimental conditions lack realism; such data might be considered optimum results and might be degraded for such more realistic conditions as return fire from the target, defensive and offensive maneuvers, and psychological factors in behavior.

These statements are quite true in regard to the data analyzed in this section. Throughout the experiment the times for firing first and subsequent rounds were collected. Ample time to fire two rounds was allowed in all tank-target engagements. Excessive time was prevalent. In no case was the gunner hurried to fire a round of ammunition. It is important to point out that the experimental conditions did not impose any requirement of firing time on the gunner except the safety requirement to engage the target within the firing-zone boundaries.

First Round

The overall difference between ammunition types in the mean firing time (first round) was 0.8 sec greater for TP-T. Although the times recorded for first-round firings of APDS-T ammunition were generally less than those of TP-T ammunition, the overall means of TP-T and APDS-T were, of course, not significantly different.

Change of lead doctrine was the most significant cause of variation in first-round firing times. An average increase of 2.7 sec resulted from the use of the modified lead doctrine. This difference was significant at the 0.15 level.

Table 16 gives the mean times to first-round fire by lead doctrine employed for combined TP-T and APDS-T ammunition.

Second Round

The overall mean time for second-round firing was 30 sec. Table 17 gives the mean times for second-round firing. The decrease in time for firing the second round with increase in target speed was significant at the 0.15 level.

TABLE 16

Mean Times for Firing First Round, by Lead Doctrine

(Combined TP–T and APDS–T ammunition)

Factor	Time for firing, sec		
	Standard doctrine	Modified doctrine	Overall mean
Target speed, mph			
5	10.5	13.6	12.0
10	8.2	5.2[a]	8.6
15	6.2	11.4	8.6
Target range			
Near	8.6	11.3	9.8
Far	8.8	11.5	10.0
Direction of target movement			
L→R	8.9	10.0	9.1
L←R	8.4	12.7	10.[illegible]
Average time	8.7	11.4	9.9

[a]Based on only one observation.

TABLE 17

Mean Times for Firing Second Round

Factor	Mean time, sec
Ammunition	
APDS–T	30.6
TP–T	29.5
Lead doctrine	
Standard	29.5
Modified	30.7
Target speed, mph	
5	36.5
10	27.8
15	25.0
Target range	
Near	29.8
Far	30.2
Direction of target movement	
L→R	28.4
L←R	31.8

Appendix A

MATHEMATICAL ANALYSIS OF LEAD AND HIT PROBABILITY

This appendix describes the mathematical analysis of theoretical determination of lead and of hit probability of the M60 tank main gun against moving ground targets. This analysis includes the derivation of equations and techniques necessary to such determinations.

LEAD

Figure A1 shows a target moving at an angle α to the horizontal coordinate. There is a firer at point C. The distance the target moves from the time it is being fired on at A to the time it is hit at B is given by Eq A1.

$$s = (v)(t) \tag{A1}$$

where s is the distance the target moves, v is the constant speed of the target,* and t is the time of flight of the round.

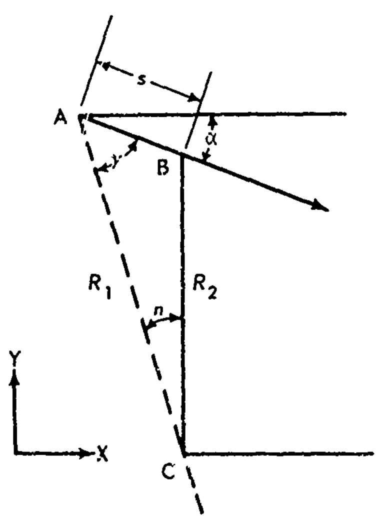


Fig. A1—Geometrical Presentation of Angular Lead n

*For nonconstant speeds $s = \int_{t_a}^{t_b} v\, dt$. t was obtained from the ballistic firing tables.[4]

Equation A2 expresses the law of cosines for triangle ABC:

$$R_2^2 = R_1^2 + s^2 - 2(R_1)(s)\cos\gamma \tag{A2}$$

where R_2 is the range of the target at time of impact with the round, R_1 is the range of the target at time of fire, and γ is the angle of attack, i.e., the angle that the direction of target motion makes with the firer's line of sight.

Since the minimum range appropriate would be 500 m, then

$$R_1 >> s$$

Therefore

$$R_2^2 \approx R_1^2$$
$$R_2 \approx R_1$$

If $R_2 = R_1 = R$, the range of the target remains approximately constant during the time of flight of the round.

Equation A3 expresses the law of sines for triangle ABC:

$$\frac{\sin n}{s} = \frac{\sin\gamma}{R} \tag{A3}$$

$$\sin n = \frac{s}{R}\sin\gamma$$

Since $R >> s$, n is very small (less than 1 deg) and $\sin n \approx n$.

Dropping the approximation sign, Eq A4 is obtained.

$$n = \frac{s}{R}\sin\gamma$$

$$n = \frac{vt}{R}\sin\gamma \tag{A4}$$

Equation A4 is an expression representing the angular lead n necessary to hit ground targets moving at constant speeds over straight paths. If v, t, and R are used within a consistent unit system, then n will be nondimensional, i.e., expressed in radians. The term $v \sin\gamma$, found within Eq A4, is the apparent velocity of the target, i.e., the component of velocity perpendicular to the line of sight.

A graph of t as a function of R (Fig. A2), the points being obtained from the ballistic firing tables,[4] reveals that $t = f(R) \approx mR$, where m is a constant. This means that the time of flight of the round is approximately a linear function of the range. This is especially true of APDS and less true for HEP, with high-explosive antitank (HEAT) ammunition lying between these two.

If $[t/R = m]$ is calculated for ranges between 500 and 2000 m and the median $\bar{m}$ is then determined, Eq A4 becomes

$$n = \bar{m}\, v \sin\gamma \tag{A5}$$

where

$$\bar{m} = \text{the mean } \frac{t}{R}$$

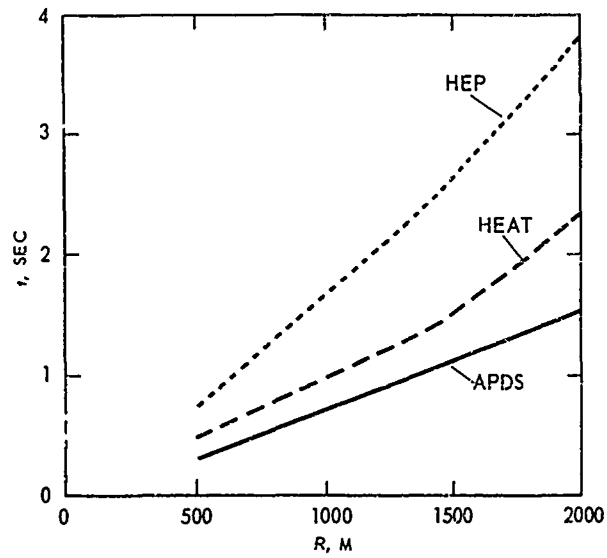


Fig. A2– Time of Flight of the Round as a Function of Target Range for Three Types of Ammunition

To be able to express the speed in meters per second, miles per hour, or feet per second and obtain the number of leads (1 lead = 5 mils), Eq A5 must be multiplied by an appropriate constant c, as follows:

$$n = c\,\bar{m}\,v\,\sin\gamma$$

Letting $K = c\bar{m}$, Eq A6 is obtained.

$$n = K\,v\,\sin\gamma \qquad \text{(A6)}$$

Values of K are given in Table A1.

Equation A6 was derived for a general case and the lead obtained by its use will be in error by less than 10 percent. The equation was programmed and run on an IBM 7090 computer.

TABLE A1

Values of *K* for Three 105-mm Ammunition Types

Ammunition type	*K*, unit of speed		
	m/sec	mph	fps
HEP	0.337	0.148	0.101
HEAT	0.200	0.088	0.060
APDS	0.143	0.063	0.043

The angle of attack γ was incremented in degrees and the speed v in meters per second. An abbreviated table of results is shown in Table A2.

TABLE A2

Effect of Variations in Target Speed and Angle of Attack on Number of 5-mil Leads Required

v, m/sec	Ammunition	γ, deg 0	30	60	90
		Required leads			
5	HEP	0	0.85	1.47	1.70
	HEAT	0	0.50	0.87	1.00
	APDS	0	0.35	0.61	0.70
10	HEP	0	1.70	2.94	3.40
	HEAT	0	1.00	1.73	2.00
	APDS	0	0.70	1.21	1.40
15	HEP	0	2.55	4.42	5.10
	HEAT	0	1.50	2.60	3.00
	APDS	0	1.05	1.82	2.10

A nomograph of Eq A6 has been constructed (see Fig. A3) that permits the making of rapid approximations of required lead. The procedure consists of laying one end of a straightedge at the given angle of attack on the appropriately marked axis. Under the type of ammunition to be used the given apparent target speed is located and projected horizontally to the appropriately marked axis, at which point the other end of the straightedge is placed. The point of intersection of the straightedge with the diagonal will be read as the required lead.

As an example in the use of the nomograph for determining required lead, suppose the angle of attack γ is 30 deg, the speed of the target v is 10 mph, and the ammunition is APDS. The dashed line illustrates the procedure on the nomograph. An answer of approximately 0.32 lead is obtained. The exact answer of 0.315 lead is obtained from Eq A6.

HIT PROBABILITY

Having determined the required lead it is now possible to calculate the theoretical hit probability. This will be outlined through a series of equations.

Horizontal

If the firer leads the target by a given amount (n'), then Eq A7 will give the angular lead error (φ).

$$\varphi = n' - n \tag{A7}$$

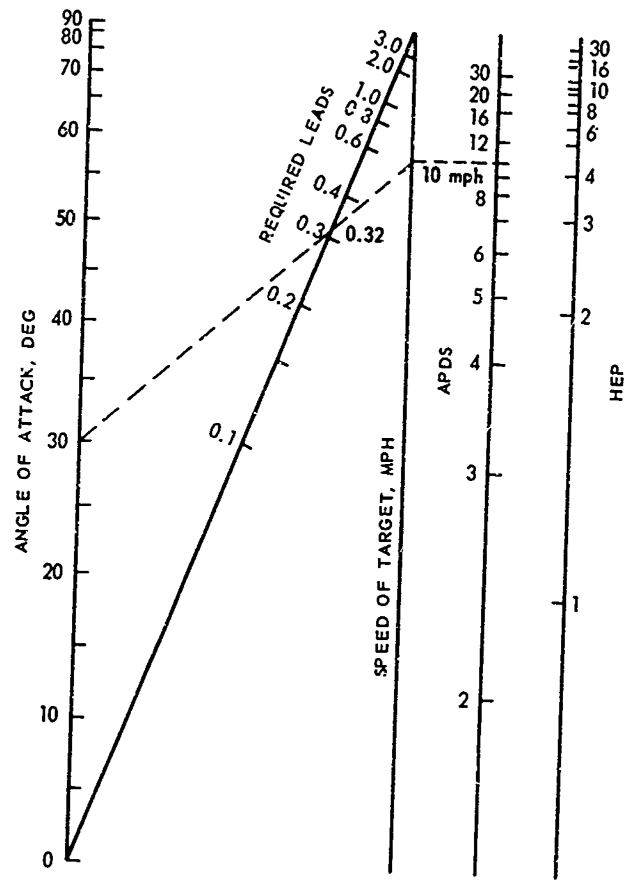


Fig. A3—Nomograph of Required Lead

$n = Kv \sin \gamma$

where n = leads required

K = ammunition constant

v = target speed

γ = angle of attack

where φ is the angular lead error, n' is the lead taken by the firer, and n is the theoretically required lead.

Figure A4 illustrates the conversion of the angular lead error to miss distance (H). For small angles of φ (in our case φ will always be less than 1 deg) these miss distances are expressible by Eq A8.

$$H_\ell = 0.0049\,(R)\,(\varphi) \tag{A8}$$

The constant 0.0049 is the factor that enables φ to be expressed in number of leads. This equation has been run on the IBM 7090 computer. R was incremented in 50-m steps between 500 and 2500 meters and φ was incremented in ¼-leads between 0 and 3 leads. An abbreviated output is presented in Table A3.

TABLE A3

Effect of Variations in Angular Lead Error and Target Range on Lead Miss Distance

φ, leads	R, m				
	500	1000	1500	2000	2500
	H_ℓ, m				
½	1.23	2.45	3.68	4.90	6.13
1	2.45	4.90	7.35	9.80	12.25
1½	3.68	7.35	11.03	14.70	18.38
2	4.90	9.80	14.70	19.60	24.50

In addition to the lead miss distance there will be a horizontal bias (H_b) due to such factors as drift, cant, droop, jump, and crosswind. These values are available.[3] The total horizontal miss distance (H_t) will be the result of addition or subtraction (depending on the relative miss directions) of these two values, as shown in Eq A9.

$$H_t = H_\ell \pm H_b \tag{A9}$$

where H_t is the total horizontal miss distance, H_ℓ is the lead miss distance, and H_b is the horizontal bias.

The target was a 6-ft-square piece of plywood.

Once the horizontal standard deviation (dispersion) has been ascertained[3] by type of round, the horizontal hit probability can be calculated. The situation is shown pictorially in Fig. A5a. Once Eqs A10 and A11 are computed, the normal distribution tables are used to find P_1 and P_2 from Z_1 and Z_2, respectively.

$$Z_1 = \frac{(X/2) + H}{\sigma_h} \tag{A10}$$

$$Z_2 = \frac{(X/2) - H}{\sigma_h} \tag{A11}$$

where σ_h is the horizontal standard deviation, X is the length of the target, and Z is a dummy variable.

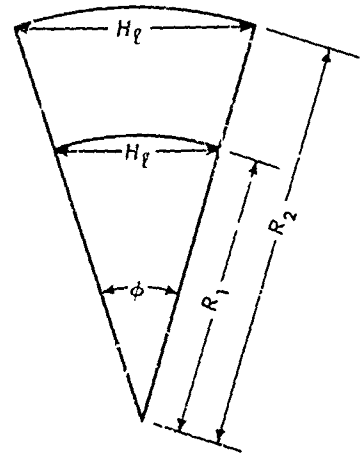
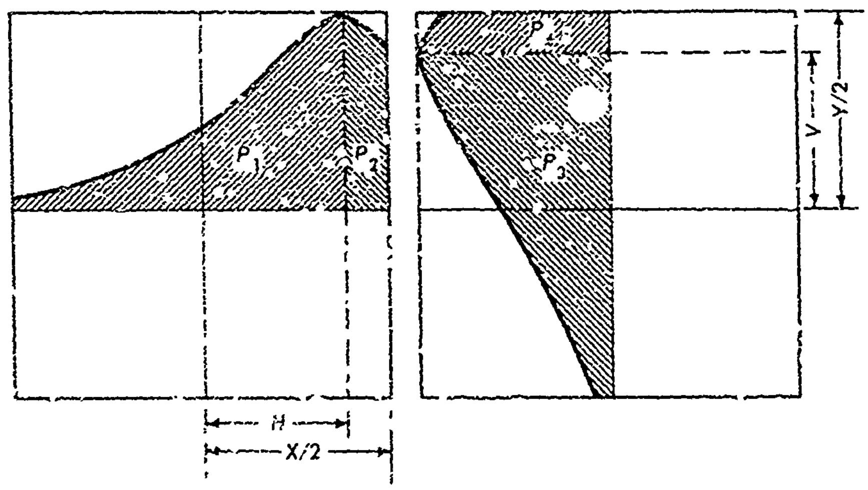


Fig. A4—Conversion of Angular Lead Error to Miss Distance

ϕ = angular lead error (less than 1 deg)
R = target range
H_ℓ = miss distance



a. Horizontal (P_h)

$$Z_1 = \frac{(X/2) + H}{\sigma_h} \rightarrow P_1$$

$$Z_2 = \frac{(X/2) - H}{\sigma_h} \rightarrow P_2$$

$$P_1 + P_2 = P_h$$

b. Vertical (P_v)

$$Z_3 = \frac{(Y/2) + V}{\sigma_v} \rightarrow P_3$$

$$Z_4 = \frac{(Y/2) - V}{\sigma_v} \rightarrow P_4$$

$$P_3 + P_4 = P_v$$

Total hit probability $(P_T) = P_h P_v$

Fig. A5—Calculation of Hit Probability

Then Eq A12 is used to find the horizontal hit probability.

$$P_h = P_1 + P_2 \tag{A12}$$

where P_h is the horizontal hit probability.

Vertical

To find the vertical hit probability the vertical bias V must be known,[3] as well as the vertical standard deviation σ_v.[3] The vertical situation is illustrated by Fig. A5b. After the parts of Eq A13 have been computed, P_3 and P_4 are found in the normal distribution tables from Z_3 and Z_4, respectively.

$$Z_3 = \frac{(Y/2) + V}{\sigma_v} \qquad Z_4 = \frac{(Y/2) - V}{\sigma_v} \tag{A13}$$

where Y is the height of the target, V is the vertical bias, and σ_v is the vertical standard deviation.

Then Eq A14 is used to find the vertical hit probability:

$$P_v = P_3 + P_4 \tag{A14}$$

P_T is given by Eq A15:

$$P_T = P_H \, P_v \tag{A15}$$

SUMMARY

The following steps outline the method of determining the hit probability of a round fired at a ground target moving at constant speed in a straight line.

Given are velocity of target v, range to target R, angle of attack γ, target size (x, y), and number of 5-mil leads taken n'. The type of ammunition used determines K, σ_h, σ_v, and H_2.

The following determinations can be made:

Lead

$$n = Kv \sin \gamma$$

Angular Lead Error

$$\omega = n' - n$$

Lead Miss Distance

$$H_\ell = 0.0049 \, (R)(\omega)$$

Total Horizontal Miss Distance

$$H_t = H_\ell \pm H_b$$

Horizontal Hit Probability

$$Z_1 = \frac{(X/2)+H}{\sigma_h} \text{ determines } P_1$$

$$P_1 + P_2 = P_h$$

$$Z_2 = \frac{(X/2)-H}{\sigma_h} \text{ determines } P_2$$

Vertical Hit Probability

$$Z_3 = \frac{(Y/2)+V}{\sigma_v} \text{ determines } P_3$$

$$P_3 + P_4 = P_v$$

$$Z_4 = \frac{(Y/2)-V}{\sigma_v} \text{ determines } P_4$$

Total Hit Probability

$$P_T = (P_h)(P_v)$$

A nomograph has been constructed (see Fig. A6) to facilitate determinations of hit probability. In using this nomograph the straightedge is placed on L/2 and on the miss-distance, upper-scale, axis. Then the straightedge is laid across the resulting intersection and the dispersion axis σ. The intersection with the diagonal gives P_1. This procedure is repeated, using the lower scale on the miss-distance axis, to derive P_2. The horizontal hit probability is the sum of P_1 and P_2. If a shift to the upper scale of the auxiliary axis is necessary, then the horizontal hit probability is the difference between P_1 and P_2. The procedure for the vertical plane is similar, using the vertical miss distance and half the height of the target. Then P_3 and P_4 are found, and the vertical hit probability is the sum of these terms.

As an example in the use of the nomograph for determining the horizontal hit probability, the horizontal dispersion of APDS and HEP at 730- and 1650-m ranges have been anchored on the dispersion axis. Suppose the target was 20 by 10 m and the miss distance using HEP at 730-m range was ½ m. Then the dashed lines on the nomograph indicate a P_1 value of 0.44 and a P_2 value of 0.23, their sum resulting in a horizontal hit probability of 0.67.[2] To find the vertical hit probability, the 10-m dimension and the vertical dispersion component are used. It is necessary to multiply the horizontal hit probability by the vertical hit probability to obtain the total hit probability.

For each round fired by the M60 tank a photographic record was obtained. The angular aimoff, in mils, from the center of mass of the moving target was measured from the film at the time of firing. The speed of the moving target was determined from the time required for the target to traverse the marked section of the track. The theoretically required lead for a center-of-mass hit on a target moving at a specific speed was determined from lead-speed-ammunition curves. The lead-lay error resulted as the difference between the film-measured lead and the required lead, also in mils, for a center-of-mass target hit. The linear miss distance (meters) followed directly from the engagement range (meters) and the angular error (mils). The horizontal hit

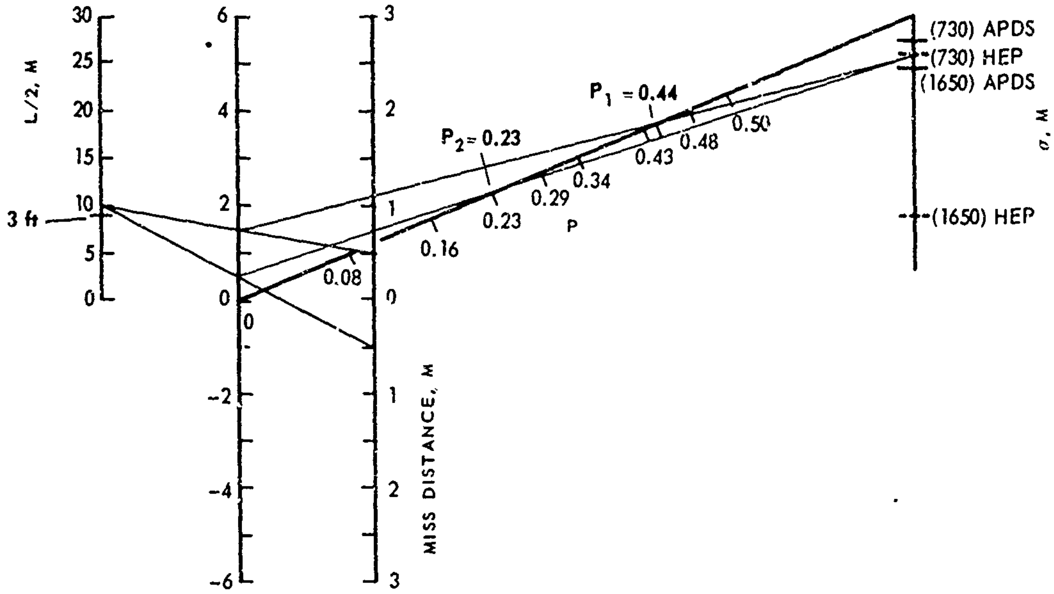


Fig. A6—Nomograph of Hit Probability

probability on the 6- by 6-ft target with the given ammunition was computed from the linear miss distance (App B) by the method presented in this appendix. The vertical hit probability was computed from the standard vertical bias and dispersion at the ranges investigated (i.e., 730 and 1650 m). These quantities for the two types of ammunition utilized are given in Table A4 for the respective ranges.

TABLE A4

Vertical Hit Probability for Two Types of Ammunition against a 6- by 6-ft Target

105-mm ammunition	Range, m	
	730	1650
APDS–T	0.88	0.51
TP–T	0.88	0.40

The total hit probability was then computed as the product of the horizontal hit probability and the standard vertical hit probability at the given range.

Appendix B

ANALYSIS OF EXPERIMENTAL DATA

Figures

Tables

The experimental data on observed target hits are given in Table B1 for the variables investigated. Table B2 gives the 5-factor analysis of variance of the data of Table B1. The means of the statistically significant (α = 0.10 or less) interactions are given in Tables B3 to B5. The inconsistencies exhibited at separate speed levels in Table B4 are greatly reduced by accumulating the data of the higher target speeds (10 and 15 mph).

The horizontal miss distances for both hits and misses are given in Table B6. Miss distances of target hits as well as misses were measured from the center of the target cross (i.e., aiming point). In case of a measured target hit in the center of the target (same as center of target cross) the miss distance is 0, 0, both horizontally and vertically. Dashes indicate unreadable gun-camera film or mechanical failure of equipment.

Tables B7 and B8 give the analyses of variance of the hit probabilities resulting from the horizontal miss distances together with the analysis described in App A for APDS-T and TP-T, respectively. The explicit significant interactions are pointed out in Figs. B1 to B4.

TABLE B1

Target Hits and Misses, Observed Data by Factor Investigated

(1 = hit, 0 = miss, — = mechanical failure)

a. APDS-T Ammunition

Lead doctrine and direction of target movement	Target speed, mph					
	5		10		15	
	Near, 730 m	Far, 1650 m	Near, 730 m	Far, 1650 m	Near, 730 m	Far, 1650 m
First Round						
Standard						
L → R						
1st trial	1	0	0	1	1	1
2d trial	0	0	0	0	0	0
L ← R						
1st trial	0	0	0	0	1	0
2d trial	1	0	0	0	0	0
Modified						
L → R						
1st trial	1	1	0	0	0	0
2d trial	1	1	1	0	0	0
L ← R						
1st trial	1	1	0	0	0	0
2d trial	1	1	1	0	0	0
Second Round						
Standard						
L → R						
1st trial	1	1	0	1	0	–
2d trial	1	0	0	0	1	0
L ← R						
1st trial	0	0	1	0	1	0
2d trial	1	0	–	0	0	0
Modified						
L → R						
1st trial	1	1	1	1	1	1
2d trial	1	1	0	1	1	0
L ← R						
1st trial	1	0	0	0	0	1
2d trial	0	0	1	–	0	1

TABLE B1--(continued)

b. TP–T Ammunition

Lead doctrine and direction of target movement	Target speed, mph 5 Near, 730 m	5 Far, 1650 m	10 Near, 730 m	10 Far, 1650 m	15 Near, 730 m	15 Far, 1650 m
First Round						
Standard						
L→R						
1st trial	0	0	0	0	0	0
2d trial	0	0	0	0	0	0
L←R						
1st trial	0	0	0	0	0	0
2d trial	0	0	0	0	0	0
Modified						
L→R						
1st trial	0	0	0	0	0	0
2d trial	0	0	0	0	0	0
L←R						
1st trial	0	0	0	0	0	0
2d trial	0	0	0	0	0	0
Second Round						
Standard						
L→R						
1st trial	0	0	0	0	0	0
2d trial	0	0	0	0	0	0
L←R						
1st trial	0	0	0	0	0	0
2d trial	0	0	0	0	0	0
Modified						
L→R						
1st trial	0	0	0	0	0	0
2d trial	1	0	0	0	1	0
L←R						
1st trial	–	0	0	0	0	0
2d trial	0	0	0	0	0	0

TABLE B2

Analysis of Variance—105-mm APDS–T Observed Hit–Miss Data (P_{HE})

Factors and combinations	Degrees of freedom	Sum of squares	Mean square	F
Round	1	0.7830	0.7830	4.372[b]
Doctrine, I	1	0.6256	0.6256	3.493[c]
Range, R	1	0.6517	0.6517	3.639[c]
Speed, S	2	1.1809	0.5904	3.296[b]
Direction, D	1	1.4186	1.4186	7.921[a]
Round × I	1	0.1465	0.1465	0.818
Round × R	1	0.0001	0.0001	0.000
Round × S	2	0.1951	0.0976	0.545
Round × D	1	0.1403	0.1403	0.783
I × R	1	0.1954	0.1954	1.091
I × S	2	0.2924	0.1462	0.816
I × D	1	0.1584	0.1584	0.884
R × S	2	0.9013	0.4506	2.516[c]
R × D	1	0.1882	0.1882	1.051
S × D	2	0.5382	0.2691	1.502
Round × I × R	1	0.1953	0.1953	1.090
Round × I × S	2	0.9789	0.4893	2.732[c]
Round × I × D	1	0.1602	0.1602	0.894
Round × R × S	2	0.0528	0.0264	0.147
Round × R × D	1	0.0007	0.0007	0.004
Round × S × D	2	0.1916	0.0958	1.535
I × R × S	2	0.6351	0.3176	1.773
I × R × D	1	0.2280	0.2280	1.273
I × S × D	2	0.3008	0.1504	0.840
R × S × D	2	0.8635	0.4318	2.411[c]
Round × I × R × S	2	0.0530	0.0265	0.148
Round × I × R × D	1	0.0036	0.0036	0.020
Round × I × S × D	2	0.2566	0.1283	0.716
Round × R × S × D	2	0.4661	0.2330	1.301
I × R × S × D	2	1.0840	0.5420	3.026[c]
Round × I × R × S × D	2	0.4755	0.2378	1.328
Error	47	8.4183	0.1791	
Replication	1	0.3348		
Total	95	22.1145		

[a] Significant at $\alpha = 0.01$. [b] Significant at $\alpha = 0.05$. [c] Significant at $\alpha = 0.10$.

TABLE B3

P_{HE} for Significant First-Order Interaction, 105-mm APDS–T Ammunition

Target speed and range

Speed, mph	Range	
	Near	Far
5	0.75	0.42
10	0.27	0.26
15	0.50	0.43

TABLE B4

P_{HE} for Significant Second-Order Interaction, 105-mm APDS–T Ammunition

a. Target Range, Speed, and Direction

Target speed, mph	L → R		L ← R	
	Near range	Far range	Near range	Far range
5	0.88	0.62	0.62	0.00
10	0.25	0.50	0.29	0.03
15	0.50	0.27	0.25	0.38
Average, 10 and 15	0.38	0.38	0.27	0.20

b. Round, Lead Doctrine, and Speed

Target speed, mph	First round		Second round	
	Standard doctrine	Modified doctrine	Standard doctrine	Modified doctrine
5	0.25	0.75	0.50	0.62
10	0.12	0.12	0.29	0.53
15	0.38	0.12	0.27	0.62
Average, 10 and 15	0.25	0.12	0.28	0.58

TABLE B5

P_{HE} for Significant Third-Order Interaction, 105-mm APDS–T Ammunition

Target speed, lead doctrine, direction of target movement, and target range

Speed, mph	Doctrine	Movement L → R		Movement L ← R	
		Near range	Far range	Near range	Far range
5	Standard	0.75	0.25	0.50	0
	Modified	1.00	1.00	0.75	0
10 and 15	Standard	0.25	0.40	0.41	0
	Modified	0.50	0.38	0.12	0.10

TABLE B6

Horizontal Miss Distances, Film Data by Factor Investigated

(+ ahead of target, − − behind target)

a. APDS-T Ammunition

Lead doctrine and direction of target movement	Target speed, mph					
	5		10		15	
	Near, 730 m	Far, 1650 m	Near, 730 m	Far, 1650 m	Near, 730 m	Far, 1650 m
	Miss distance, m					
First Round						
Standard						
L→R						
1st trial	−1.13	+8.09	−1.13	−1.16	+0.04	+4.29
2d trial	+0.47	+5.86	+0.58	+4.21	+1.24	−3.39
L←R						
1st trial	−0.61	−6.44	−2.99	−5.94	−2.63	−4.13
2d trial	+0.07	−3.71	+0.55	+7.51	+3.87	−6.02
Modified						
L→R						
1st trial	−0.22	−1.40	0.55	+9.98	−1.35	–
2d trial	0	−3.05	−0.61	–	−0.73	+0.74
L←R						
1st trial	+0.55	−1.82	−1.35	2.72	−2.08	−6.11
2d trial	+0.95	−1.98	−0.18	−2.23	+1.35	0
Second Round						
Standard						
L→R						
1st trial	−1.13	+4.79	−1.13	−0.61	−0.58	–
2d trial	+0.47	+6.27	+0.58	−1.57	−0.40	−8.75
L←R						
1st trial	−10.30	−7.67	−0.91	−5.12	−2.81	−3.71
2d trial	+1.17	–	–	8.33	+5.15	–
Modified						
L→R						
1st trial	−1.50	−0.91	+0.04	−0.30	−0.99	+0.91
2d trial	0	−3.05	–	+0.15	−0.73	+0.74
L←R						
1st trial	−0.30	−3.05	−1.35	+2.23	−1.72	−0.15
2d trial	+1.13	−1.98	+1.10	–	–	−0.42

TABLE B6—(continued)

b. TP–T Ammunition

Lead doctrine and direction of target movement	Target speed, mph: 5 — Near, 730 m	5 — Far, 1650 m	10 — Near, 730 m	10 — Far, 1650 m	15 — Near, 730 m	15 — Far, 1650 m
	Miss distance, m					
First Round						
Standard						
L→R						
1st trial	−1.83	+16.58	–	−6.60	−7.85	+4.13
2d trial	−0.51	−0.41	+1.86	–	−10.18	−15.91
L←R						
1st trial	+0.44	–	−4.02	−1.65	−1.64	–
2d trial	−2.37	+1.32	+0.69	−10.56	−7.30	–
Modified						
L→R						
1st trial	−0.40	−4.54	−2.01	−7.43	0	−0.91
2d trial	+0.84	–	–	–	−0.69	–
L←R						
1st trial	–	−10.40	–	−12.87	−3.98	–
2d trial	+0.88	−0.83	−0.04	−2.06	−3.72	+6.11
Second Round						
Standard						
L→R						
1st trial	–	+24.83	–	−8.25	−9.31	–
2d trial	−0.33	−7.84	−5.62	–	−5.26	+13.20
L←R						
1st trial	−0.84	–	−2.01	+0.41	−3.10	–
2d trial	−2.37	+2.97	+0.69	+2.54	–	−15.26
Modified						
L→R						
1st trial	+0.33	–	–	−8.25	–	+0.74
2d trial	+0.30	–	–	–	−0.05	–
L←R						
1st trial	–	−0.50	–	+4.46	–	–
2d trial	+0.05	−0.41	−2.19	−2.06	–	+6.52

SECRET

TABLE B7

Analysis of Variance—P_{HL} of 105-mm APDS–T Ammunition

Source	Degrees of freedom	Sum of squares	Mean square	F
Round	1	0.0024	0.0024	0.088
Doctrine, I	1	0.1408	0.1408	5.196[b]
Range, R	1	2.3932	2.3932	88.309[a]
Speed, S	2	0.1426	0.0713	2.631[c]
Direction, D	1	0.4858	0.4858	17.926[a]
Round × I	1	0.0459	0.0459	1.694
Round × R	1	0.0185	0.0185	[illegible]
Round × S	2	0.0692	0.0346	1.277
Round × D	1	0.0003	0.0003	0.011
I × R	1	0.0301	0.0301	1.122
I × S	2	0.0158	0.0079	0.292
I × D	1	0.0192	0.0192	0.708
R × S	2	0.6111	0.3055	11.273[a]
R × D	1	0.1607	0.1607	5.930[b]
S × D	2	0.3052	0.1526	5.631[a]
Round × I × R	1	0.0000	0.0000	0.000
Round × I × S	2	0.0000	0.0000	0.000
Round × I × D	1	0.0267	0.0267	0.985
Round × R × S	2	0.0935	0.0468	1.727
Round × R × D	1	0.0127	0.0127	0.469
Round × S × D	2	0.0688	0.0344	1.269
I × R × S	2	0.1401	0.0700	2.583[c]
I × R × D	1	0.9728	0.9728	35.897[a]
I × S × D	2	0.0940	0.0470	1.734
R × S × D	2	0.3322	0.1661	6.129[a]
Round × I × R × S	2	0.0366	0.0183	0.675
Round × I × R × D	1	0.0000	0.0000	0.000
Round × I × S × D	2	0.0000	0.0000	0.000
Round × R × S × D	2	0.0000	0.0000	0.000
I × R × S × D	2	0.0000	0.0000	0.000
Round × I × R × S × D	2	0.0000	0.0000	0.000
Error	38	1.0299	0.0271	
Replications	1	0.1753		
Total	86	7.2783		

[a]Significant at $\alpha = 0.01$.
[b]Significant at $\alpha = 0.05$.
[c]Significant at $\alpha = 0.10$.

TABLE B8

Analysis of Variance—P_{HL} of 105-mm TP–T Ammunition

Source	Degrees of freedom	Sum of squares	Mean square	F
Round	1	0.0012	0.0012	0.0508
Doctrine, I	1	0.1395	0.1395	5.9110[a]
Range, R	1	0.9330	0.9330	39.5339[c]
Speed, S	2	0.2712	0.1356	5.7458[a]
Direction, D	1	0.0122	0.0122	0.5169
Round × I	1	0.0000	0.0000	0.0000
Round × R	1	0.0005	0.0005	0.0212
Round × S	2	0.0137	0.0068	0.2881
Round × D	1	0.0005	0.0005	0.0212
I × R	1	0.0000	0.0000	0.0000
I × S	2	0.0985	0.0492	2.0847
I × D	1	0.1943	0.1943	8.2330[a]
R × S	2	0.2214	0.1107	4.6907[a]
R × D	1	0.0000	0.0000	0.0000
S × D	2	0.2077	0.1038	4.3983[a]
Round × I × R	1	0.2258	0.2258	9.5678[b]
Round × I × S	2	0.0368	0.0184	0.7797
Round × I × D	1	0.0035	0.0035	0.1483
Round × R × S	2	0.0229	0.0114	0.4830
Round × R × D	1	0.0241	0.0241	1.0212
Round × S × D	2	0.0682	0.0341	1.4449
I × R × S	2	0.1770	0.0885	3.7500[a]
I × R × D	2	0.1418	0.0709	3.0042
I × S × D	2	0.0956	0.0478	2.0254
R × S × D	2	0.0000	0.0000	0.0000
Round × I × R × S	2	0.0000	0.0000	0.0000
Round × I × R × D	1	0.0000	0.0000	0.0000
Round × I × S × D	2	0.0050	0.0025	0.1059
Round × R × S × D	2	0.0662	0.0331	1.4025
I × R × S × D	2	0.0000	0.0000	0.0000
Round × I × R × S × D	2	0.0000	0.0000	0.0000
Error	16	0.3771	0.0236	0.0000
Replications	1	0.0602		
Total	65	3.3377		

[a]Significant at $\alpha = 0.05$.
[b]Significant at $\alpha = 0.01$.
[c]Significant at $\alpha = 0.005$.

Target Speed—Target Range

Target range						Target speed, mph					
Near			Far			5		10		15	
Target speed, mph						Target range					
5	10	15	5	10	15	N	F	N	F	N	F

$\alpha = 0.05$ $\alpha = 0.10$ $\alpha = 0.10$

Target Speed—Target Direction

Target direction						Target speed, mph					
L→R			L←R			5		10		15	
Target speed, mph						Target direction					
5	10	15	5	10	15	L→R	L←R	L→R	L←R	L→R	←R

$\alpha = 0.05$ $\alpha = 0.05$

Target Range—Target Direction

Target range				Target direction			
Near		Far		L→R		L←R	
Target direction				Target range			
L→R	L←R	L→R	L←R	N	F	N	F

$\alpha = 0.05$ $\alpha = 0.01$ $\alpha = 0.01$

Fig B1—Schematic Diagram of Explicit Significant Differences of Means, First-Order Interactions, P_{HL} of APDS-T

Any two means of variables not underlined by the same line are significantly different at the significance level (α) indicated.

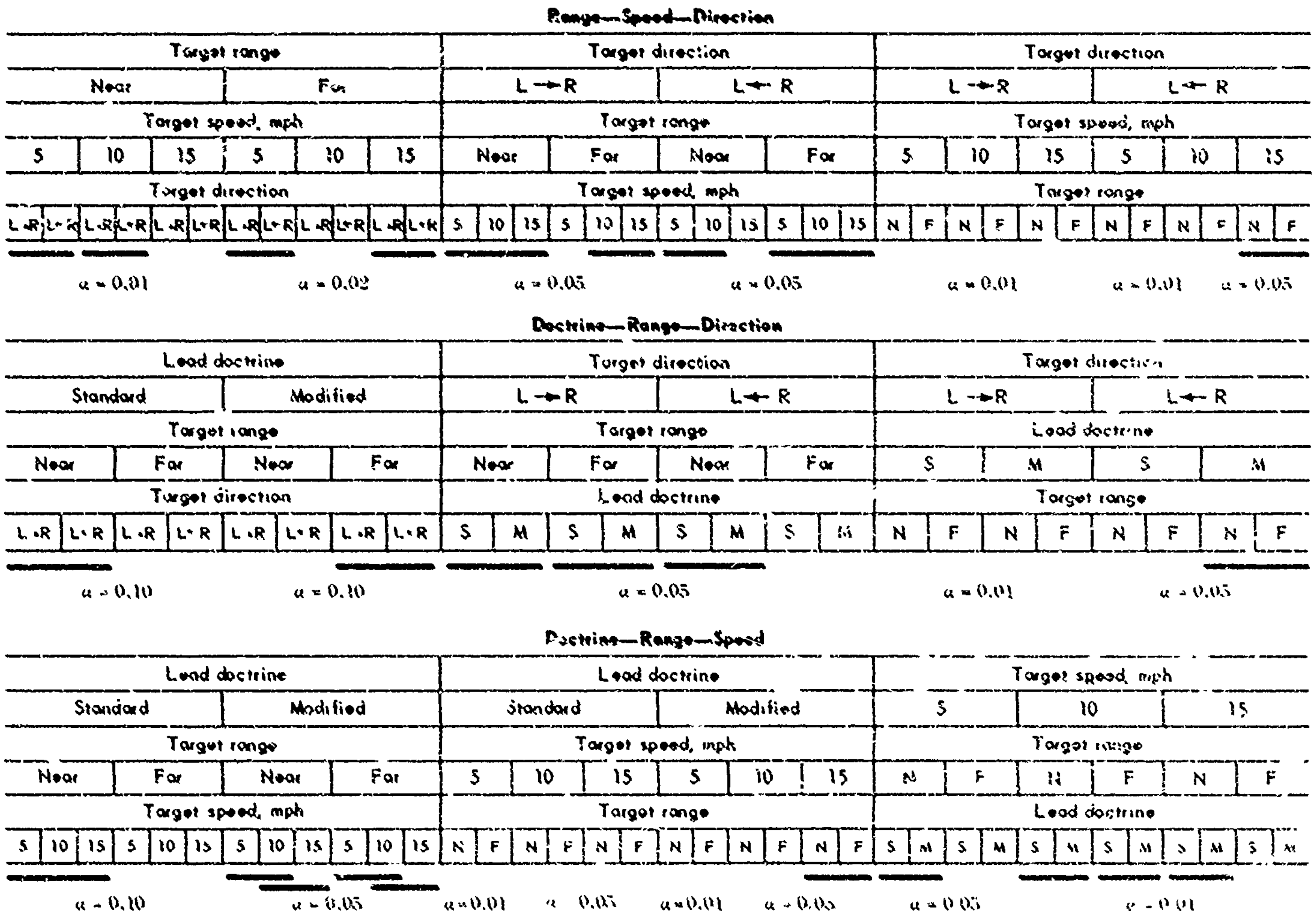


Fig. B2—Schematic Diagram of Explicit Significant Differences of Means, Second-Order Interactions, P_{HL} of APDS–T

Any two means of variables not underlined by the same line are significantly different at the significance level (α) indicated.

SECRET

Target Speed—Target Range

Target range						Target speed, mph					
Near			Far			5		10		15	
Target speed, mph						Target range					
5	10	15	5	10	15	Near	Far	Near	Far	Near	Far

$\alpha = 0.10$ $\alpha = 0.01$ $\alpha = 0.10$

Target Speed—Target Direction

Target direction						Target speed, mph					
L←R			L→R			5		10		15	
Target speed, mph						Target direction					
5	10	15	5	10	15	L→R	L←R	L→R	L←R	L→R	L←R

$\alpha = 0.10$ $\alpha = 0.05$ $\alpha = 0.05$ $\alpha = 0.10$

Lead Doctrine—Target Direction

Target direction				Instruction			
L←R		L→R		Standard		Modified	
Lead doctrine				Target direction			
Standard	Modified	Standard	Modified	L←R	L→R	L←R	L→R

$\alpha = 0.05$

Fig. B3—Schematic Diagram of Explicit Significant Differences of Means, First-Order Interactions, P_{HL} of TP–T

Any two means of variables not underlined by the same line are significantly different at the significance level (α) indicated.

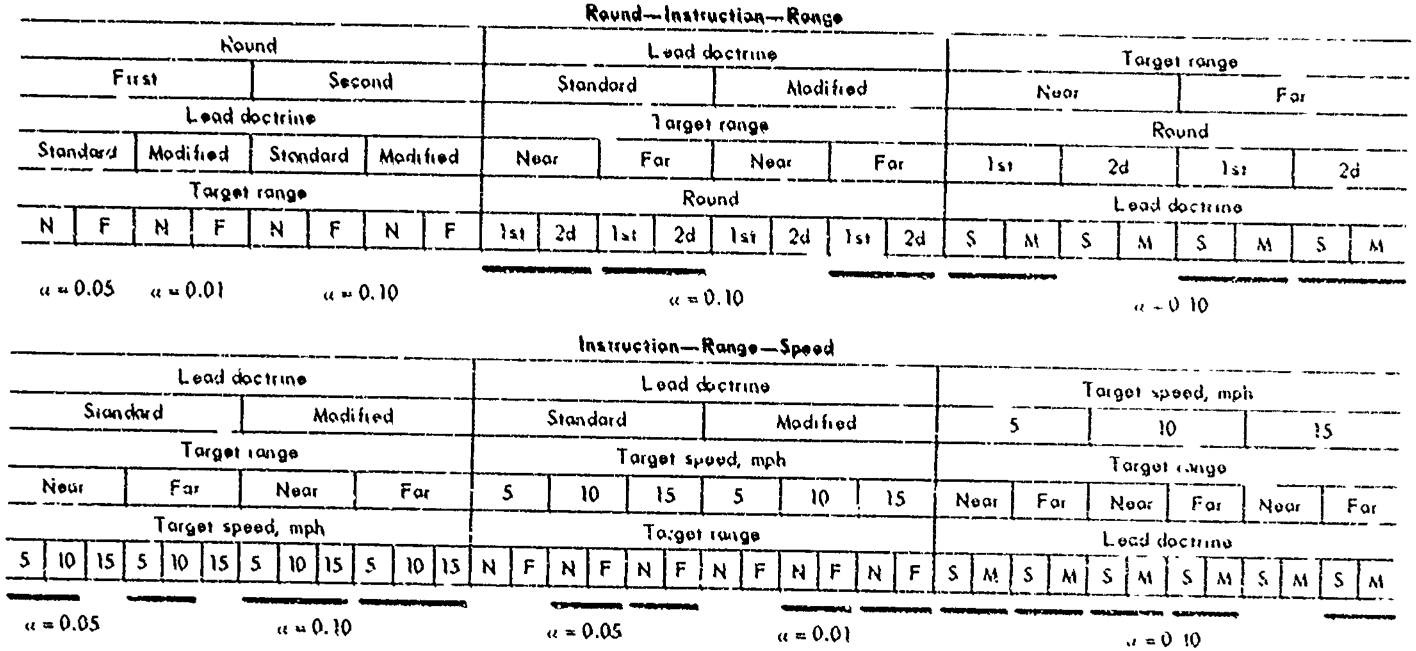


Fig. B4—Schematic Diagram of Explicit Significant Differences of Means, Second-Order Interactions, P_{HL} of T°–F

Any two means of variables not underlined by the same line are significantly different at the significance level (α) indicated.

Appendix C

DATA-COLLECTION METHODS AND FORMS USED

Figures

Table

Figure C1 shows the form used by the observers using the BC scope and/or the rangefinder (M17c) of the M60 tank for recording sensings of rounds fired. The order in which data were collected is shown in Table C1.

Figure C2 shows the handout that was distributed to personnel who operated under the standard lead doctrine.

Figure C3 is the table of required leads that was distributed to the personnel who operated under the modified lead doctrine.

Figure C4 shows the form used in collection of data directly from the target. Material for marking holes in the target was supplied to the target crew.

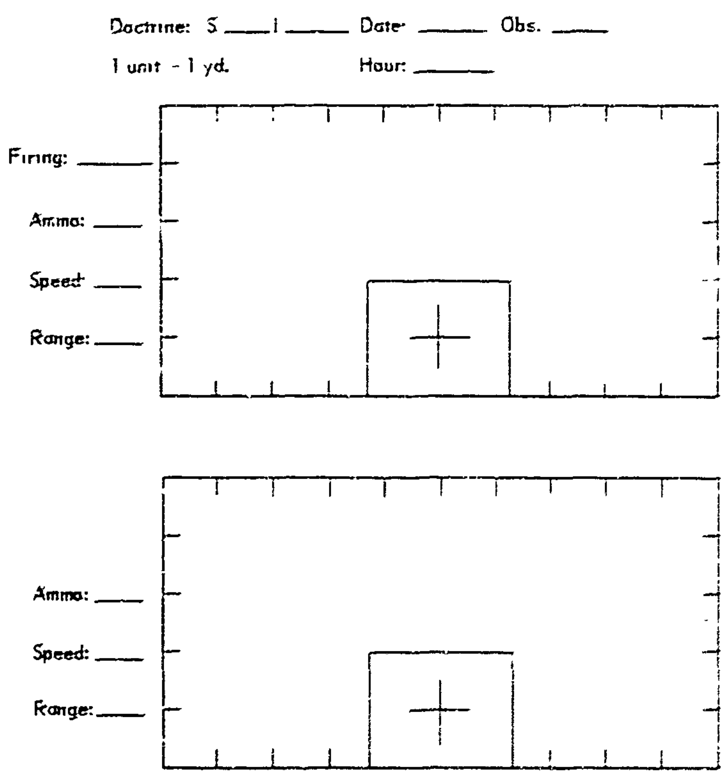


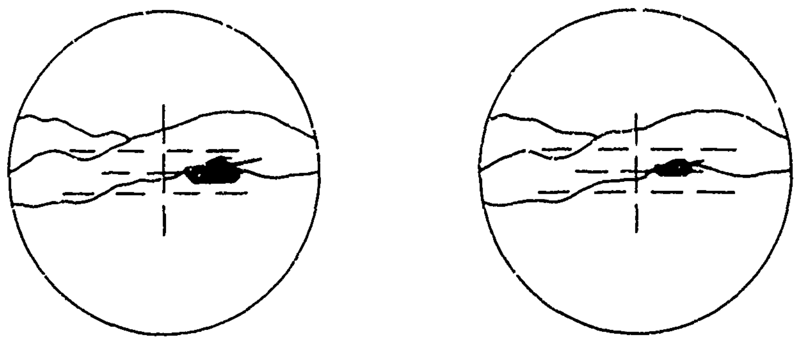
Fig. C1—Form for Observer Sensing

TABLE C1

Order of Data Collection

Firing number	Gunner number		Target speed, mph	Target range		Direction of target movement
	HEP	APDS		HEP	APDS	
			Standard Lead Doctrine			
1	2	3	10	N[a]	F[b]	L← R
2	4	1	5	F	N	L← R
3	3	2	10	F	N	L← R
4	2	3	15	F	N	L← R
5	1	4	5	N	F	L← R
6	3	2	15	N	F	L← R
7	2	1	5	N	F	L→R
8	4	3	15	N	F	L→R
9	3	4	10	N	F	L→R
10	4	3	10	F	N	L→R
11	3	4	15	F	N	L→R
12	1	2	5	F	N	L→R
13	4	1	15	F	N	L← R
14	3	2	5	N	F	L← R
15	1	4	15	N	F	L← R
16	4	1	10	N	F	L← R
17	1	4	10	F	N	L← R
18	2	3	5	F	N	L← R
19	1	2	15	F	N	L→R
20	2	1	10	F	N	L→R
21	1	2	10	N	F	L→R
22	3	4	5	F	N	L→R
23	4	3	5	N	F	L→R
24	2	1	15	N	F	L→R
			Modified Lead Doctrine			
25	7	6	10	F	N	L← R
26	6	7	10	N	F	L← R
27	5	8	5	N	F	L← R
28	6	7	15	F	N	L← R
29	8	5	5	F	N	L← R
30	7	6	15	N	F	L← R
31	8	7	15	N	F	L→R
32	7	8	10	N	F	L→R
33	7	8	15	F	N	L→R
34	6	5	5	N	F	L→R
35	8	7	10	F	N	L→R
36	5	6	5	F	N	L→R
37	7	6	5	N	F	L← R
38	5	7	5	F	N	L← R
39	8	5	10	N	F	L← R
40	8	5	15	F	N	L← R
41	5	8	15	N	F	L← R
42	5	8	10	F	N	L← R
43	6	5	15	N	F	L→R
44	8	7	5	N	F	L→R
45	5	6	10	N	F	L→R
46	7	8	5	F	N	L→R
47	5	6	15	F	N	L→R
48	6	5	10	F	N	L→R

[a] Near range, 730 m.
[b] Far range, 1650 m.



a. Sight picture for 1 lead ahead of a moving target at 1000-m (yd) range.

b. Sight picture for 1 lead ahead of same moving target at 2000-m (yd) range. Target appears smaller due to greater range, but lead is the same.

Fig. C2—Illustration of Leading Moving Targets (Ref 2, p 130)

If the gunner fires a round with the gun aimed directly at a moving target, the target will move out of the path of the projectile, causing it to miss the target. To compensate for this movement, the gun is aimed ahead of the target so the projectile and target will meet. This technique is called leading. The gunner measures lead by use of the lead lines on the reticle of his direct-fire sight. One lead equals 5 mils and is measured from the center of vulnerability.

REQUIRED LEAD

	Target Moving Left to Right (→)			
	730-m Range		1650-m Range	
Speed (mph)	HEP	APDS	HEP	APDS
5	½	0	½	0
10	1½	½	1½	½
15	2	1	2	1

REQUIRED LEAD

	Target Moving Right to Left (←)			
	730-m Range		1650-m Range	
Speed (mph)	HEP	APDS	HEP	APDS
5	½	0	1	0
10	1½	½	2	½
15	2	1	2½	1

Fig. C3—Tables of Required Leads, Supplied to Users of Modified Lead Doctrine

Target Data Collection Form Date:

Firing	Direction	Ammo	Target Speed	Range	Round #	Target		Observed As?	Miss Distance (Feet)		Remarks
						Hit	Miss		Hor.	Vert.	

Fig. C4—Data Form for Pit Personnel

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